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Phytotoxicity of Sodium Fluoride and Uptake of Fluoride to Willow Trees

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Intro and scope

Fluoride (F) is present in pristine air, soil and water. As exposure to F through food and beverages is unavoidable, the effects of F on human and mammalian health have been intensely investigated. Due to continued use of super phosphate fertilizers, F accumulates in agricultural soils. However, little is known about the phytotoxicity of sodium fluoride (NaF) and the uptake of F when exposed through roots.

The aim of this study is to:

1) Assess the phytotoxicity of NaF to willows when taken up through the roots

2) Determine the uptake of F to willows when taken up through roots

3) Describe the uptake of F to willows with a non-linear mass balance model

Experimental setup – the willow tree tox test

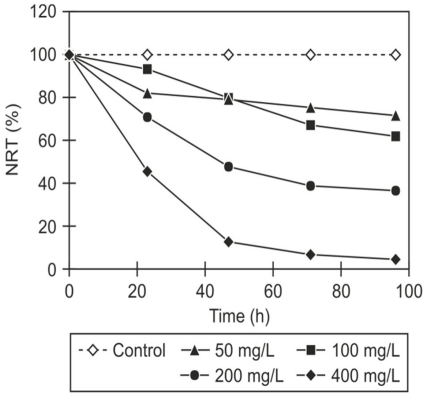
- 40 cm willow sticks (Salix viminalis) were pre-grown and transferred to Erlenmeyer flasks
- Trees were exposed to solutions of various NaF concentrations
- Test duration: 96 h
- Normalized Relative Transpiration (NRT) used as test parameter:

$$NRT(C,t)(\%) = \frac{\frac{1}{n}\sum_{i=1}^{n} T_i(C,t)/T_i(C,0)}{\frac{1}{m}\sum_{j=1}^{m} T_j(0,t)/T_j(0,0)} \times 100$$

Where,
C) Conc.; t) Time period; T) Abs. transpiration; i and j) Replicate no.; n) No. of replicates; m) No. of controls see Trapp et al (2008)

Phytotoxicity results

- Toxic effects observed within 48 h for conc. >100 mg F L^{-1}
- Clear dose-response relationship
- No statistically significant difference between toxicity of 50 mg F L^{-1} and 100 mg F L^{-1}
- Wilting of the trees exposed to 400 mg F L^{-1}



Model description and output

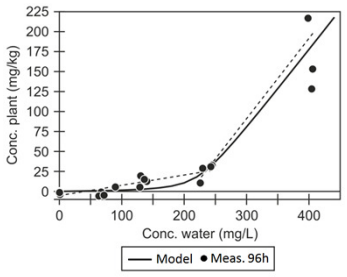
$$0 = \underbrace{\frac{K_M Q C_W}{M_R}}_{\text{Uptake by transp.}} + \frac{Q C_R C_R}{M_R} - \underbrace{\frac{K_M Q C_R}{M_R K_{RW}} - \frac{C^2_R Q}{M_R K_{RW}}}_{\text{Translocation}} - \underbrace{K_M k_R C_R - k_R C^2_R - v_{max} C_R}_{\text{Growth}}$$

Enzymatic removal

where,
K_M) Half saturation constant; Q) Transpiration; C_W) Conc. in external solution; M_R) Mass of roots; C_R) Conc. in roots; K_{RW}) Conc. ratio root/water; k_R) Root growth rate and v_{max}) Max. enzymatic removal rate see Trapp et al (2008)*

The model assumes:

- Steady state
- Passive uptake of F with the transpiration stream
- Enzymatic removal described by Michaelis-Menten kinetics



Model parameterization

- Maximal enzymatic removal rate, v_{max}: 9 g F kg^{-1} d^{-1}
- Breakthrough point (BTP): 210 mg F L^{-1} – On a molar basis the same as obtained by Trapp et al. (2008)* for chloride (Cl)
- Uptake slope approx. 1 for C > BTP – unhindered transport with water

Parameter	Value	Unit	Origin
Conc. In solution, C_W	0-400	mg L^{-1}	Measured
Root mass, m_R	0.001	Kg	Estimated
Transpiration stream, Q	0.04	L d^{-1}	Measured ave.
Half-saturation constant, K_M	2	g L^{-1}	Fitted
Max. Enzymatic removal rate, v_{max}	8.992	g kg^{-1} d^{-1}	Fitted
Root growth rate, k_R	0	d^{-1}	Estimated

	Equation	Valid conc.	R^2	n	P
Regression 1	y = 0.128x – 5.186	C < 209.5	0.764	16	<< 0.001
Regression 2	y = 1.005x – 210.5	C > 209.5	0.790	8	< 0.005

* Trapp S, Feificova D, Rasmussen N F, Bauer-Gottwein P, 2008, Plant uptake of NaCl in relation to enzyme kinetics and toxic effects, Environ. Exp. Bot., 64, 1-7

Conclusions

- NaF is phytotoxic at levels of EC_{10}: 38.0±34.2; EC_{20}: 59.6±40.7 and EC_{50}: 128±51 (values in mg F L^{-1} ±95% confidence interval)
- Uptake of F can be described by a non-linear mass balance model assuming enzymatic removal
- At external concentrations above 210 mg F L^{-1} the willows can no longer pump out F from the plant cells and start to accumulate F
- Enzymatic removal of F and Cl from plant cells is likely to be managed by the same “pump”-system

For more details, see: Lauge PW Clausen, Ulrich G Karlson and Stefan Trapp, 2014, Phytotoxicity of Sodium Fluoride and Uptake of Fluoride to Willow Trees, International Journal of Phytoremediation (In press)